Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Experimental Assessment of the Two-Phase Flow in a Large Inclined Channel

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1. Introduction

In the case of severe accident, the core catcher system plays an important role in mitigating the consequences. It can prevent the reaction between the molten corium and the concrete basement which leads to the hydrogen gas generation and the spread of radioactive materials into the containment. The core catcher system is able to retain the corium and provide adequate cooling by natural circulation.

The integrity of the core catcher plate is crucial for retaining the corium in stable state. The natural circulation flow rate and the structure of two-phase flow in the coolant channel impose the limits on cooling capability of the core catcher system. The heat flux and CHF conditions are determined by the natural circulation flow rate and local void distribution. In order to assess the cooling performance of the core catcher system, a model facility has been constructed in POSTECH using scaling analysis [1], [2]. This facility consists of horizontal, inclined and vertical section. To investigate the flow parameters in each section, the instrumentation is developed to measure two-phase characteristics such as local void fraction, bubble velocity and bubble size. To date, there has been a considerable amount of research conducted on the internal structure of two-phase flow in pipe. However, the number of attempts made on the experiment regarding large inclined channels has been still limited. One of the reasons for this lack of data is the difficulty in constructing experimental facility. In this paper, the parameters of the flow in the inclined section are presented. The inclined channel is 10 degree from the horizontal with the rectangular cross section of 300 cm^2. The distributions of local parameters are evaluated through the data of double sensor conductivity probes installed at different locations along the inclined section.

2. Experimental facility

2.1 Test facility

Figure 1 shows the horizontal and inclined section of test facility which is developed to provide experimental verification on the cooling performance of the core catcher system. The test section is made of transparent polycarbonate in order to enable visualization. The horizontal section is 0.3m in length and 0.719m in height. The length of the inclined section is 2.618m and its height is 0.1m. Both these sections are 0.3m in width. Air is injected from the top through the 800 µm pore size of metal foam. In horizontal and inclined section, there are four air inlets as can be seen in Figure 1. Air flow rate is controlled by rotameter (FLD114',OMEGA).

Fig. 1. Horizontal and inclined section of the test facility

2.2 Instrumentation

The double sensor conductivity probe is employed to measure two-phase flow parameters. This technique has been extensively developed by S. T. Revankar and M. Ishii [3], W. H. Leung and S. T. Revankar [4]. The method is based on the instantaneous measurement of local electrical resistivity around the sensor in the two-phase system by a sensor electrode. In Figure 2, each sensor works independently in order to identify phase surrounding that tip by means of the difference between the gas and the liquid electrical resistivity.

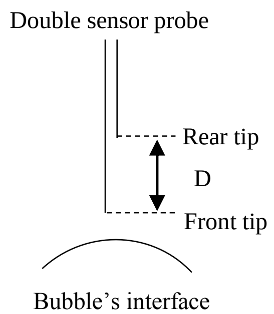

Fig.2. Double sensor probe and bubble's interface

When the tip contacts air and water, the circuit is opened and closed respectively. The voltage of output, therefore, fluctuates between two reference values. When the sensor contacts the water and air, the voltage output is high and low respectively. Figure 3 describes the signal of a double sensor probe.

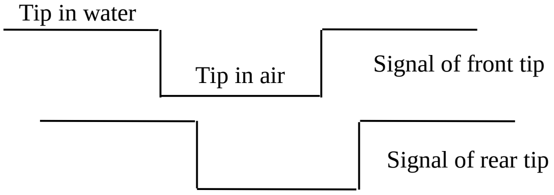

Fig.3. Double sensor probe signal

The double sensor probe measurement devices consists of probes, control box, connection box and data acquisition system. The schematic of the measurement is delineated in Figure 10.

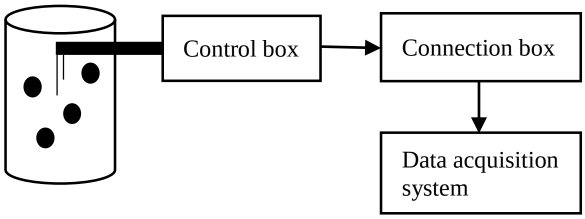

Fig.4. Schematic of the double sensor probe measurement

Fig.5. Double sensor conductivity probe

Because the number of bubbles detected in each sampling is large and a lot of calculations has to be performed in order to figure out the flow characteristics, a Visual Basic (VB) program is created to process the data obtained from probes. All the parameters related to experiment's conditions can be input into the VB program.

3. Experiment and Results

3.1 Experiment setup

In the experiment, only the horizontal and inclined section are filled with water. The surface of water is kept below the top of the inclined section during the experiment. The amount of water pumped into the sections, therefore, is fixed and no water moving in or out the sections during the experiment. Air is injected through the air inlet as described in Figure 6. The volumetric flow rate of air injected is set at 100 liters per minute.

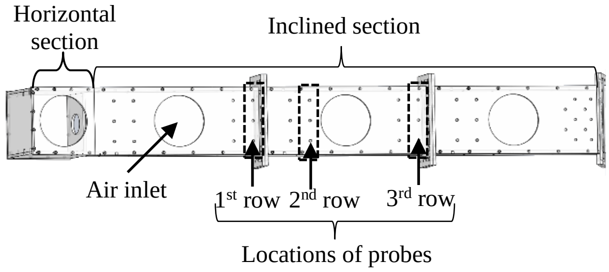

Fig.6. Schematic of the test section and probes' locations in the experiment

There are 9 probes used in the experiment. They were arranged in 3 rows with 3 probes in each row along the width of the inclined section as described in Figure 6. The axial distances from the first, second and the third row of probes to the center of the air inlet were 0.375m, 0.6646m and 1.2146m respectively. In each row, the probes had the same axial location but located 0.1m apart. The probes get the data of void fraction, bubble velocity and bubble chord length of the two-phase flow in the channel. In order to plot the profile of each parameter, the probes were positioned at seven different distances from the top surface of the inclined section: 0.5cm, 1cm, 1.5cm, 2cm, 2.5cm, 3cm and 3.2cm. Beyond 3.2cm, almost no bubble exists so it is not necessary to put the probes outside 3.2cm. For each location, each probe got the data in 30s. The process of acquiring data was repeated 10 times to calculate the mean value of each parameters. The signal of probes was acquired at 10000 samples/s. This frequency is high enough to capture the flow behavior in the channel.

3.2 Results and Discussion

The void fraction profiles obtained in the first, second and the third row of probes are presented in Figure 7a, b and c respectively. Here the non-dimensional distance from the top wall of the inclined section is defined as the ratio of the distance of the tip sensor from the top wall to the height of the inclined section (d/H). In each location of a probe, the void fraction can be calculated from either the data of front or rear tip. Therefore, the mean value of them is chosen as void fraction at that location. From these figure, it is clear that there is no significant difference between the data of probes belonging to the same row. That means, in the same axial locations, void fraction is distributed evenly. Because of the similarity between probes in a row, the void fraction of the probe located in the middle of its row is considered as the void fraction of that row. Figure 8 presents the comparison between void fractions obtained from 3 rows of probes. In this Figure, no significant difference between void fraction profiles is observed. This result shows that the void fraction profile does not change much when the two-phase flow moves along the inclined section. To a certain extent, it is because there is only one air inlet which was used in the experiment.

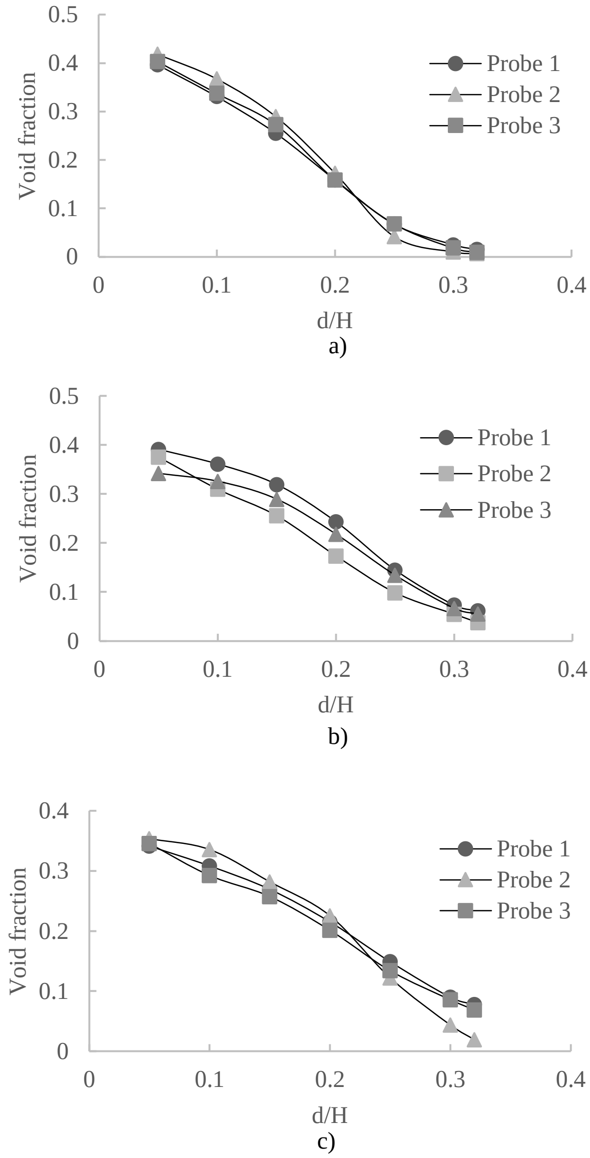

Fig.7. Void fraction profiles at different rows of probes. At each row, probe 1, probe 2 and probe 3 are placed at the same axial location: (a) the first row; (b) the second row; (c) the third row

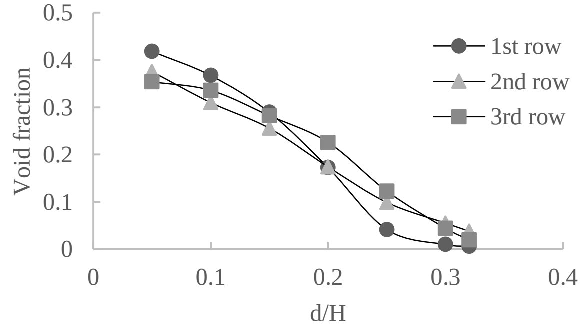

Fig.8. Comparison of void fraction profiles obtained from 3 rows of probes

With regard to flow regime in the inclined section, the slug flow occurs in the channel. The air was injected through metal foam with 800μm pore size which is able to generate small bubbles. After being injected to the channel, small bubbles rapidly coalesce and form the elongated bubbles moving along the top surface wall of the inclined section. At the tail of each large bubble, an eddy exists which is essentially a mixing vortex. In this mixing zone, gas is trapped due to the violent mixing operation [5].

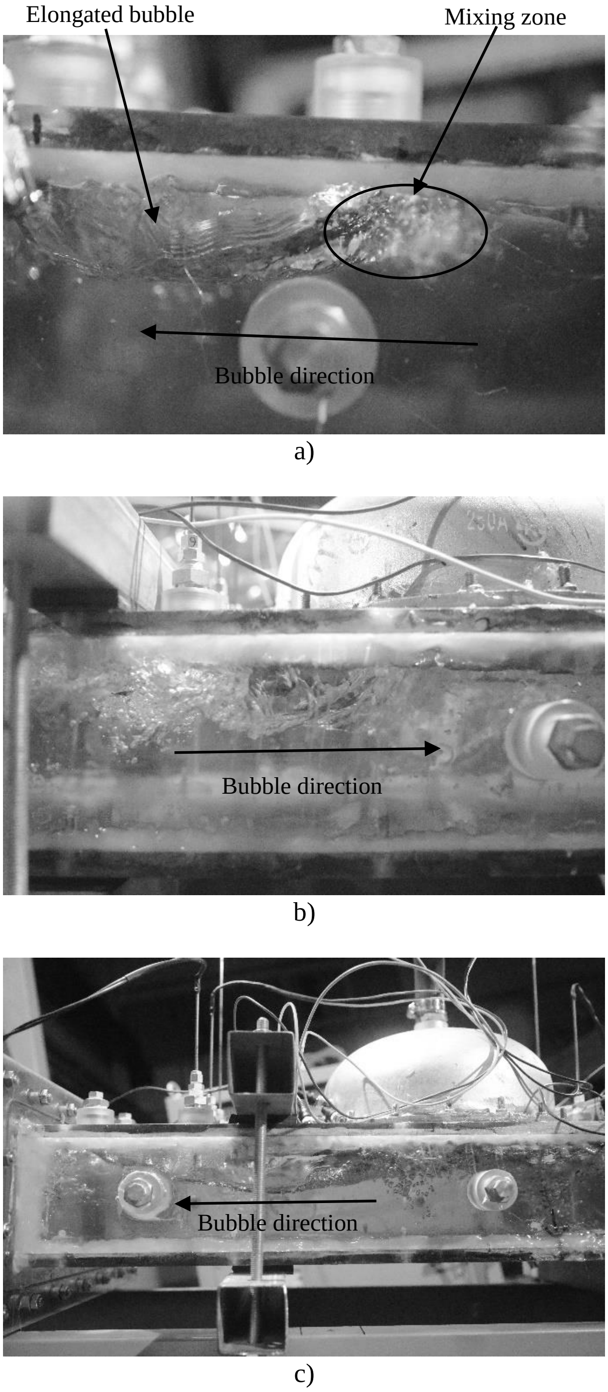

Fig.9. Flow regime in the inclined section: (a) Near the first row of probes; (b) Near the second row; (c) Near the third row

As seen in Figure 9, small bubbles existing at the tails of elongated bubbles are strongly influenced by the mixing vortices so their movement is very turbulent. Because of this phenomenon, the velocity of small bubbles is not possible to be measured. The probes were used to measure the translational velocity of the elongated bubbles. The result shows that the mean velocities are 0.97m/s, 0.86m/s, 0.83m/s at the first, second and third row of probes respectively. The difference between these values is insignificant since it is within the uncertainty of the probes which is estimated about 20%. It means that the translational velocity of elongated bubbles is almost constant along the inclined section. Based on the data of the probes, the mean bubble chord length of elongated bubbles at the first, second and third row of probes is 14.4cm, 12.8cm and 17cm respectively. The difference between the values at the first and second row of probes is insignificant since it can be caused by probes' uncertainty and these two locations are close to each other. However, the difference in the bubble chord length between the first and the third row of probes shows that the bubbles are elongated further when the flow moves upward. The result of bubble chord length of the probes is verified through the pictures of DSLR camera. The comparison between two methods shows a good agreement.

4. Conclusions

The data sets of the structure of two-phase flow in an inclined large channel was acquired. The air was injected through the metal foam installed on the top surface wall of the inclined section. Water level was kept below the top of the inclined section so the amount of water was fixed during the experiment. 9 probes set up at the different locations to get the data of local two-phase parameters. The measurement at each location was conducted in 5 minutes to determine the mean value of each parameter. The result of local void fraction profiles at different locations indicates that the void distribution primarily changes along the height of the inclined section. The slug flow occurs in the channel which results in most bubbles attached to the top surface wall. This fact explains the high local void fraction near the top wall and its rapid decline towards the bottom wall of the inclined section. The translational velocity as well as the chord length of elongated bubbles were estimated. The result of double sensors probes was validated by means of DSLR camera. The speed of camera's shutter was set at 1000 frames per second in order to capture the flow behaviors.

The cooling performance of core catcher system can be assessed by means of the data sets of internal structure of the two-phase flow in the inclined section. This experiment provides some initial information about the flow behaviors in the core catcher system. From this data, the later experiment can be developed to get the full data sets of a whole system. As a result, the limitations of the cooling capability of core catcher system can be determined and good designs of this system can be proposed.

ACKNOWLEDGEMENTS

This work was performed under the auspices of Korea Atomic Energy Research Institute (KAERI).

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